

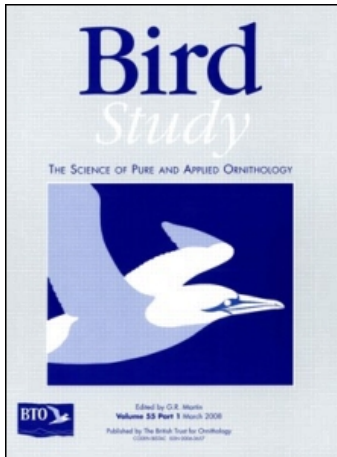
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# Long-term trends in the abundance of breeding Lapwing *Vanellus vanellus* in relation to land-use change on upland farmland in southern Scotland

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**Capsule** A long-term decline on this habitat is shown to be associated with the intensification of agricultural management, particularly the occurrence of field drainage.

**Aims** To assess long-term trends in the number of breeding Lapwing and determine the relationship between these trends and changes in agricultural management on an upland study area.

**Methods** Breeding Lapwing were counted along two road transects in nine years between 1980 and 2002, and on one extensive plot in 1980, 1990 and 2000. Counts along the road transects were made from a vehicle and the fields used for nesting were recorded. Changes in field management along the transects were monitored annually between 1980 and 1990, and habitat composition assessed in 1980, 1985, 1990 and 2000.

**Results** During the first 20 years of study the number of breeding Lapwing declined substantially on all three count areas and by 77% overall, with further declines on both transects in 2002. The area of unimproved grassland and arable on these transects also declined substantially due to conversion to improved grass. Fields that comprised either unimproved grassland or arable were most likely to hold nesting Lapwing, while the chance of a field losing its nesting Lapwing was positively associated with the occurrence of drainage. Drainage and conversion to improved grass were closely linked.

**Conclusions** Agricultural intensification is a probable cause of decline in the number of breeding Lapwing in upland areas. Such declines may have been widespread in upland areas following increased agricultural intensification in recent decades.

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The number of breeding Lapwing *Vanellus vanellus* has declined widely over much of western Europe during the past two to three decades (Hagemeier & Blair 1997, Wilson *et al.* 2001, Henderson *et al.* 2002). These declines have been attributed mainly to reduced productivity, below the levels needed to balance adult mortality and maintain population stability (Galbraith 1988, Baines 1990, Peach *et al.* 1994, Catchpole *et al.* 1999). Lapwing are highly dependent upon agricultural land-uses, particularly livestock and cereal production, for the provision of suitable breeding habitat, and the main causes of reduced productivity appear to be linked to the intensification of agricultural management. Specifically, increased nest losses from

more intensive cultivation regimes, replacement of spring-sown cereals by autumn-sown cereals causing loss of suitable nesting habitat, the loss of mixed farming systems causing separation of nesting and chick-rearing habitat, increased predation of nests following grassland improvement and increases in stocking densities have all been identified as causes of lower breeding success (Beintema & Muskens 1987, Galbraith 1988, Baines 1990, Shrubbs 1990, Berg *et al.* 1992, Johansson & Blomqvist 1996, Hart *et al.* 2002).

Within the UK, the available data on Lapwing population trends suggest a 'moderate' decline over the past two decades, sufficient to qualify Lapwing for amber, but not red, listing in terms of its conservation status (Gregory *et al.* 2002). However, information on the timing and extent of Lapwing declines in the UK varies regionally, with the most detailed data arising from lowland habitats in the south of the country (O'Brien & Smith 1992). Thus, between 1987 and

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1998 Lapwing numbers declined by 49% in England and Wales (Wilson *et al.* 2001), whilst in Northern Ireland a decline of 66% was recorded over a similar period (Henderson *et al.* 2002). Associated with this, Common Bird Census data (derived primarily from southern, lowland sites) suggest that Lapwing numbers were relatively stable from the late 1960s until the early 1980s, since when there has been a steep and sustained decline (Crick *et al.* 1998). By comparison, relatively limited data, spanning fewer years, are available from Scotland, where over 50% of the UK breeding population occurs (Wilson & Browne 1999, O'Brien *et al.* 2002). In Scotland, the number of breeding pairs was estimated to have declined by 8% between 1992 and 1997, although this decline was not statistically significant (O'Brien *et al.* 2002). Few data exist to allow any assessment of population trends prior to 1992, although there is evidence of a contraction in breeding range in the northwest since the late 1960s (Gibbons *et al.* 1993).

We document changes in the number of breeding Lapwing in a predominantly pastoral upland farmland area in southern Scotland, between 1980 and 2002. Data on associated changes in agricultural practice are presented, and the relationships between those changes and Lapwing abundance are investigated.

## METHODS

### Study area

The study area was adjacent to West Linton, Peebleshire (approximately 55°45'N, 3°21'W) and consisted of two transects and a single extensive plot. Both transects were located along minor roads, with the first (Carlops) being 7.5 km in length (approximately 55°47'N, 3°20'W to 55°45'N, 3°17'W) and the second (Romano Bridge) being 6.0 km in length (approximately 55°43'N, 3°21'W to 55°40'N, 3°20'W). The transects included all fields that were fully visible from the roadside, so that the Carlops transect comprised 38 fields with a total area of 2.46 km<sup>2</sup> and the Romano Bridge transect comprised 62 fields with a total area of 2.88 km<sup>2</sup>. The extensive plot (55°45'N, 3°19'W) was 14.8 km<sup>2</sup> in area, with the west boundary adjacent to part of the Carlops transect. Altitude ranged from 240–285 m asl on the Carlops transect, 190–350 m asl on the Romano Bridge transect and 200–300 m asl in the extensive plot. Each of these areas comprised mainly enclosed fields, although several discrete sections of unenclosed land were included on the Romano Bridge transect.

### Lapwing counts

Both transects were surveyed in seven years between 1980 and 1992, and again in 2000 and 2002, whilst the extensive plot was surveyed in 1980, 1990 and 2000 (Fig. 1). In each survey year, five surveys were conducted along each transect, at approximately weekly intervals, between the first week in April and the first half of May, coinciding with the main nesting period of Lapwing in northern Britain (Barratt & Barratt 1984, Galbraith 1988). Surveys were conducted from the roadside and almost exclusively from within a vehicle, and nests were not visited. Thus, the risk of observer activities affecting nesting success was minimized (Picozzi 1975, Götmark 1992). During each survey of a transect, the number of Lapwing present was recorded, along with the number observed sitting on nests in each broad habitat-type and the individual fields in which these sitting birds were observed. Total numbers of Lapwing were used as the count unit, rather than assumed numbers of pairs, because of the complex breeding system of this species, in which polygamy is widespread and double brooding can occur (Parish *et al.* 1997a, 1997b).

Surveys of the extensive plot consisted of one count only in each year of survey. This count was conducted during the first week of May, when counts of sitting Lapwing were usually highest along the two transects. Many of the fields in this plot could not be viewed from roadsides so that counts were made by walking alongside, or into, fields, and counting the number of Lapwing present from suitable vantage points. Thus, counts in this plot were limited to total numbers and did not include sitting birds.

### Field management

At the start of the study, all farmers with land along the two transects were contacted to provide details of each field and, for grassland, the year in which each was last improved by ploughing and reseeded. Based on this, fields were classified either as unimproved if there was no record of improvement within the 40 years prior to 1980, or as improved with three age categories since last reseeded: 1–4, 5–9 and 10–40 years. This time period coincided with the period for which the farmers' records of field management were most complete at the start of the study, while the intervals used reflected a combination of the precision of these records (changes within the past 10 years being known to the exact year) and the need for adequate samples for analysis. Unimproved

grassland was typically uneven in topography and vegetation structure, with varying amounts of tussocky vegetation, and was characterized by the presence of rushes *Juncus* spp., sedges *Carex* spp. and in some cases Harestail Cotton-grass *Eriophorum vaginatum*. Improved fields were more uniform, both in topography and vegetation, and typically had swards within which species such as Ryegrass *Lolium perenne*, Crested Dogstail *Cynosurus cristatus* and Clover *Trifolium repens* were common. Fields were classified as arable if they were ploughed or contained developing crops in April. Crops were mostly spring-sown barley, oats and turnips.

Between 1980 and 1990 one of the observers (I.R.T.) drove along each transect between three and five times a month throughout each year, and recorded any instances of field drainage or improvement by ploughing and reseeded. Changes in field management were not recorded between 1990 and 2000, so by 2000 data were no longer available on the time since last improvement of grasslands. Thus in 2000, grasslands were classified subjectively as improved or unimproved based solely upon their appearance and the species present in the sward, as described above. This was undertaken by the second observer (M.C.G.), without prior knowledge of the past management on each of the fields. Details of the full habitat composition along both transects were recorded in 1980, 1985, 1990 and 2000.

For all fields included on the two transects, and each discrete section of unenclosed land on the Romano Bridge transect, area, altitude and slope were measured from Ordnance Survey 1:25 000 scale maps.

## Analyses

Logistic regression analyses were performed to determine the factors associated with field occupation by nesting Lapwing in 1980, 1990 and 2000, and those associated with the loss of nesting Lapwing from fields between 1980 and 1990 and between 1990 and 2000. These analyses were performed using GLIM (Aitkin *et al.* 1989), specifying a binomial error distribution and logit link function, with the binomial denominator set to 1 (Crawley 1993).

Whether fields were used for nesting (as determined by recording the presence of sitting birds) was analysed in relation to altitude, slope, transect (Carlops or Romano Bridge), field-type and field area. Field-type was classified as unenclosed rough grazing, arable, unimproved grassland and, in 1980 and 1990, grassland improved 1–4 years previously, 5–9 years previously and 10–40 years previously. Due to the lack of detailed data

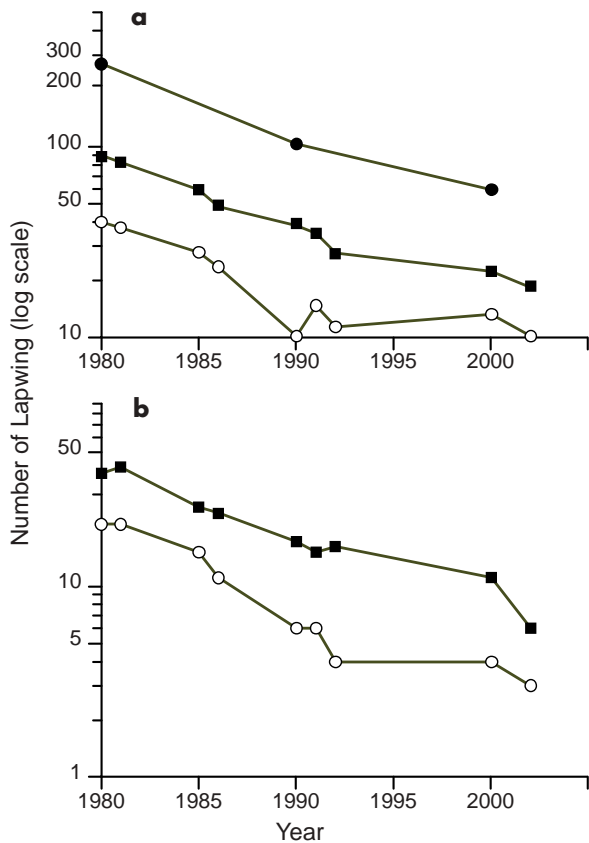
on field management in the later years, a single category was used for all improved grassland in the 2000 analysis. The analyses of changes in field use considered only those fields in which Lapwing had been recorded as nesting during each of the relevant periods, although the 1980 to 1990 analysis excluded data from the three fields afforested during this period. Whether a field had lost nesting Lapwing over the relevant period, as opposed to retaining or gaining them, was analysed in relation to altitude, slope, transect and, for the 1980 to 1990 analysis, whether or not the field had been drained and whether or not the field had either been reseeded or converted from arable to grass. For the 1990 to 2000 analysis, the habitat change variables were restricted to whether or not the field had been converted to improved grassland.

Step-down procedures were used to determine the significant main effects in these analyses, fitting a model that included all independent variables, omitting each of these in turn and recalculating the model excluding that effect. The effect with the lowest significance level was then deleted from the model and the process repeated until only significant effects remained. The effects of first-order interactions were assessed in the analyses of field occupation, adding each of these in turn to the main effects model determined from the initial step-down process. If the addition of any interactions produced a significant change in model deviance, then the most significant interaction was incorporated in the model. All main effects were then retested for significance and the process repeated until all significant interactions had been incorporated. Interactions were not considered in the analyses of changes in field use as this resulted in the equation having too many parameters to converge on a solution. Significance testing for the logistic analyses was undertaken by treating the difference in the deviance ( $-2 \times \log$  likelihood) of the models that did and did not include the effect as  $\chi^2$ , with the appropriate degrees of freedom (equivalent to the number of parameters removed from the model). Data were checked for overdispersion in the logistic analyses (Crawley 1993). Two-tailed significance levels are used throughout, accepting significance at the level  $P \leq 0.05$ .

## RESULTS

### Trends in Lapwing numbers

Over the study period, Lapwing numbers declined on both transects and on the extensive plot (Fig. 1). The



**Figure 1.** Trends in the numbers of Lapwing counted along two road transects and on a single extensive plot (a) and in the numbers of Lapwing observed sitting on nests along the two transects (b) during the study period. For each year of data, counts of individuals represent the mean from five surveys on each transect, but are derived from a single survey on the extensive plot. For nesting birds, the maximum count from the five surveys is used. ●, Extensive plot; ■, Carlops transect; ○, Romano Bridge transect.

pattern of decline on the transects was similar irrespective of whether the data were expressed as the mean count of all individual birds or the maximum count of sitting birds from the five surveys in each year. Between 1980 and 2000, Lapwing numbers declined from 88 to 22 on the Carlops transect, from 41 to 13 on the Romano Bridge transect, and from 278 to 60 on the extensive plot, based upon the mean counts for the transects and the single counts for the extensive plot. By 2002, numbers had declined further to 18 and 10, on the Carlops and Romano Bridge transects, respectively.

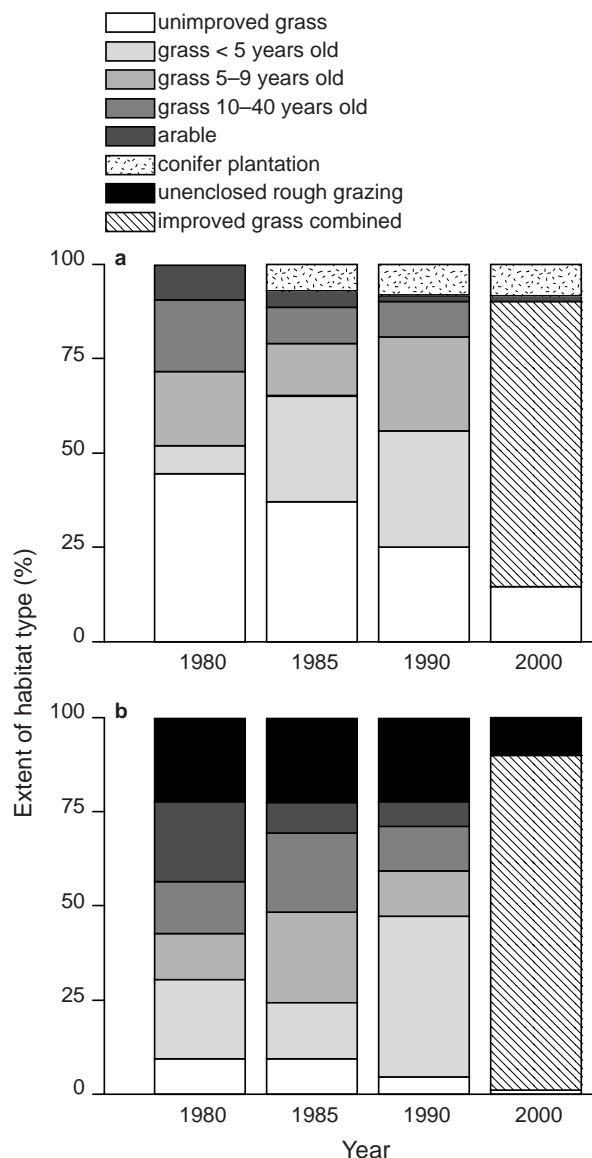
Rates of decline were highest during the earlier years of study on both the Romano Bridge transect and the extensive plot, with a significantly greater decline in numbers between 1980 and 1990 than between 1990 and 2000 (Romano Bridge,  $\chi^2 = 8.43$ ,  $df = 1$ ,  $P < 0.01$ ,

based upon mean counts; the extensive plot,  $\chi^2 = 4.20$ ,  $df = 1$ ,  $P < 0.05$ ). However, on the Carlops transect there was no significant difference in the rate of decline between the first and second half of the study period ( $\chi^2 = 0.32$ ,  $df = 1$ ,  $P = 0.57$ , based upon mean counts). These trends remained unchanged for both transects when the 2002 data were considered, and the decline between 1980 and 1990 compared with that between 1990 and 2002. Not surprisingly, birds occupied progressively fewer fields as the study progressed, with the number of fields in which nesting was recorded declining from 24 to four on the Carlops transect and from 17 to three on the Romano Bridge transect between 1980 and 2002.

### Trends in field management on transects

At the start of the study, habitats on both transects were dominated by grassland, but with more unimproved grassland on the Carlops transect (45% of the survey area compared to 9%) and less recent ( $\leq 5$  years old) improved grassland (7% of the survey area compared to 21%) than on the Romano Bridge transect. Additionally, over 20% of the Romano Bridge transect comprised arable habitats, compared with 9% of the Carlops transect.

Habitat changes were similar on both transects. Thus between 1980 and 1990, over 40% of the area of unimproved grassland was lost from both transects, while arable virtually disappeared from the Carlops transect and was reduced to 6% of the Romano Bridge transect (Fig. 2). During this period, the area of grassland that had been improved within the previous five years increased fourfold on the Carlops transect and doubled on the Romano Bridge transect. Additionally, three unimproved grassland fields on the Carlops transect (8% of the survey area) were afforested between 1980 and 1990. Based on field characteristics, 12 fields were classed as unimproved grassland in 2000. However, this included three fields that were known to have been improved during earlier years (two being in the 5–9 year class, and one in the 10–40 year class in 1990), so that these were reclassified accordingly. Thus, by 2000 the extent of unimproved grassland appeared to have declined further, to 15% (representing seven fields) and 1% (representing two fields) of the Carlops and Romano Bridge transects, respectively, with fields classed as improved grassland comprising 69% and 87% of the two transects, respectively (Fig. 2). On the Romano Bridge transect, the area of improved grass-



**Figure 2.** Changes in the extent of different habitat-types between 1980 and 2000, along two road transects located in upland farmland in southern Scotland. The Carlops transect (a) encompassed an area of 2.46 km<sup>2</sup>, while the Romano Bridge transect (b) encompassed an area of 2.88 km<sup>2</sup>. Detailed information on field management was available between 1980 and 1990 only, so that a single category for all improved grass was used for 2000 (see text).

land included approximately 50% of the land that had remained as unenclosed rough grazing until at least 1990. No arable remained on the Romano Bridge transect, and a single ploughed field (1.6% of the survey area) was present on the Carlops transect in 2000.

Drainage was recorded in four fields on each transect between 1980 and 1985, and on a further six fields on the Carlops transect and eight fields on the Romano

Bridge transect between 1985 and 1990. Of the 22 fields in which drainage was recorded, 14 of the 15 grassland fields were also reseeded at some stage between 1980 and 1990 (including five that were unimproved in 1980), while the remaining seven were converted from arable to grassland. No data were available on the occurrence of drainage after 1990.

### Factors affecting field occupation by nesting Lapwing

The highest densities of nesting Lapwing were recorded during the earlier years of the study on arable on both transects and on unimproved grassland on the Carlops transect (Table 1). On both transects, densities tended to be higher on arable and unimproved grassland than on improved grassland, except where the areas of these apparently preferred habitats had been greatly reduced in the later years of study. No nesting Lapwing were recorded on the unenclosed rough grazings on the Romano Bridge transect in any year.

Differences between these three broad habitat categories in the proportion of fields occupied by nesting Lapwing were similar to those for nesting densities, but with the differences between the two categories of grassland tending to be less marked (Table 1). Analyses of field occupation revealed significant differences between field-types in 1980 and 1990, but not in 2000 (Table 2). In 1980 the probability of field occupation also increased with field area, while in 1990 there was a significant interaction between habitat and field area. In both earlier years, fields were more likely to be occupied on the Carlops transect than on the Romano Bridge transect, while the likelihood of occupation declined with increasing slope. By 2000, nesting was recorded in 11 fields only, with interactions between field area and both slope and transect being the only significant effects detected (Table 2). The minimal adequate models (MAMs) produced in these analyses explained 57% and 69% of total deviance in 1980 and 1990, respectively, but just 23% in 2000.

The 1980 analysis suggested a lower likelihood of occupancy in most improved grassland than in either unimproved grassland or arable, although in 1990 these differences were less clear, with field-type and transect highly confounded (as unimproved grasslands comprised only 5% of the survey area on the Romano Bridge transect; Fig. 2), and a significant interaction occurring between field-type and field area (Table 2). When the effects of field-type on field occupation were considered alone, the resulting parameter coefficients

**Table 1.** Field occupation and densities of nesting Lapwing by year and broad habitat category, on two study transects. Numbers of nesting Lapwing were determined by counts of 'sitting' birds, using the maximum count in each year to calculate density (see Methods).

| Transect      | Year | Fields occupied (% mean $\pm$ sd) <i>n</i> = number of fields |                                     |                                     | Density <sup>a</sup> (no./km <sup>2</sup> ) <i>n</i> = no. of sitting birds |                     |                       |
|---------------|------|---|-------------------------------------|-------------------------------------|---|---------------------|-----------------------|
|               |      | Unimproved grass  | Improved grass                      | Arable                              | Unimproved grass  | Improved grass      | Arable                |
| Carlops       | 1980 | 65.0 ( $\pm$ 10.7)<br><i>n</i> = 20                           | 56.2 ( $\pm$ 12.4)<br><i>n</i> = 16 | 100.0 ( $\pm$ 0.0)<br><i>n</i> = 2  | 24.6<br><i>n</i> = 27   | 7.0<br><i>n</i> = 8 | 17.9<br><i>n</i> = 4  |
|               | 1985 | 50.0 ( $\pm$ 11.7)<br><i>n</i> = 18                           | 29.4 ( $\pm$ 11.0)<br><i>n</i> = 17 | 100.0 ( $\pm$ 0.0)<br><i>n</i> = 1  | 20.6<br><i>n</i> = 19   | 3.2<br><i>n</i> = 4 | 27.8<br><i>n</i> = 3  |
|               | 1990 | 35.7 ( $\pm$ 12.8)<br><i>n</i> = 14                           | 30.0 ( $\pm$ 10.2)<br><i>n</i> = 20 | 100.0 ( $\pm$ 0.0)<br><i>n</i> = 1  | 17.7<br><i>n</i> = 11   | 3.1<br><i>n</i> = 5 | 29.4<br><i>n</i> = 1  |
|               | 2000 | 28.6 ( $\pm$ 17.0)<br><i>n</i> = 7                            | 14.8 ( $\pm$ 6.8)<br><i>n</i> = 27  | 0.0 ( $\pm$ 0.0)<br><i>n</i> = 1    | 19.8<br><i>n</i> = 7  | 2.2<br><i>n</i> = 4 | 0.0<br><i>n</i> = 0   |
| Romano Bridge | 1980 | 30.0 ( $\pm$ 14.5)<br><i>n</i> = 10                           | 11.8 ( $\pm$ 5.5)<br><i>n</i> = 34  | 76.9 ( $\pm$ 11.7)<br><i>n</i> = 13 | 10.9<br><i>n</i> = 3  | 2.9<br><i>n</i> = 4 | 22.9<br><i>n</i> = 14 |
|               | 1985 | 20.0 ( $\pm$ 12.6)<br><i>n</i> = 10                           | 9.8 ( $\pm$ 4.6)<br><i>n</i> = 41   | 66.7 ( $\pm$ 19.2)<br><i>n</i> = 6  | 7.3<br><i>n</i> = 2   | 2.9<br><i>n</i> = 5 | 34.3<br><i>n</i> = 8  |
|               | 1990 | 0.0 ( $\pm$ 0.0)<br><i>n</i> = 7                              | 2.1 ( $\pm$ 2.1)<br><i>n</i> = 47   | 100.0 ( $\pm$ 0.0)<br><i>n</i> = 3  | 0.0<br><i>n</i> = 0   | 2.1<br><i>n</i> = 4 | 11.2<br><i>n</i> = 2  |
|               | 2000 | 0.0 ( $\pm$ 0.0)<br><i>n</i> = 2                              | 8.8 ( $\pm$ 3.7)<br><i>n</i> = 57   | –                                   | 0.0<br><i>n</i> = 0   | 1.6<br><i>n</i> = 4 | –                     |

<sup>a</sup>Standard errors cannot be calculated as the overall number of 'sitting' birds was recorded by habitat only, and not by individual field.

**Table 2.** Coefficients and changes in deviance for parameters included in minimal adequate models (MAMs) of the probability of a field being occupied by nesting Lapwing in three different years. Detailed data on field-types were available in 1980 and 1990 only (see text). Models were produced by logistic regression analysis; changes in deviance are those associated with removal of the parameter from the MAM.

| Year | Parameter                  | Coefficient ( $\pm$ 1 se) | Change in deviance | df | <i>P</i> |
|------|----------------------------|---------------------------|--------------------|----|----------|
| 1980 | Constant                   | -0.61 ( $\pm$ 0.78)       |                    |    |          |
|      | Transect (Romano)          | -1.64 ( $\pm$ 0.83)       | 4.19               | 1  | < 0.05   |
|      | Field-type:                |                           | 29.67              | 5  | < 0.001  |
|      | IG < 5 years               | -1.16 ( $\pm$ 1.06)       |                    |    |          |
|      | IG 5–9 years               | 0.11 ( $\pm$ 1.04)        |                    |    |          |
|      | IG 10–40 years             | -3.34 ( $\pm$ 1.38)       |                    |    |          |
|      | Arable                     | 2.42 ( $\pm$ 1.19)        |                    |    |          |
|      | Unenclosed grazing         | -13.49 ( $\pm$ 21.05)     |                    |    |          |
|      | Slope                      | -1.34 ( $\pm$ 0.58)       | 6.47               | 1  | < 0.05   |
|      | Field area (ha)            | 0.58 ( $\pm$ 0.16)        | 23.33              | 1  | < 0.001  |
| 1990 | Constant                   | -1.18 ( $\pm$ 1.33)       |                    |    |          |
|      | Transect (Romano)          | -11.17 ( $\pm$ 4.60)      | 26.69              | 1  | < 0.001  |
|      | Field-type:                |                           | 17.45              | 5  | < 0.01   |
|      | IG < 5 years               | 13.59 ( $\pm$ 6.00)       |                    |    |          |
|      | IG 5–9 years               | 8.87 ( $\pm$ 7.49)        |                    |    |          |
|      | IG 10–40 years             | -30.14 ( $\pm$ 29.85)     |                    |    |          |
|      | Arable                     | 21.11 ( $\pm$ 375.80)     |                    |    |          |
|      | Unenclosed grazings        | 11.22 ( $\pm$ 83.53)      |                    |    |          |
|      | Slope                      | -3.86 ( $\pm$ 1.72)       | 8.62               | 1  | < 0.01   |
|      | Field-type*field area (ha) |                           | 16.80              | 5  | < 0.01   |
| 2000 | Constant                   | -3.28 ( $\pm$ 1.20)       |                    |    |          |
|      | Slope*field area (ha)      | -0.36 ( $\pm$ 0.15)       | 8.94               | 1  | < 0.05   |
|      | Transect*field area (ha)   | 0.72 ( $\pm$ 0.33)        | 6.35               | 1  | < 0.05   |
|      | IG < 5 years*area          | -1.43 ( $\pm$ 0.63)       |                    |    |          |
|      | IG 5–9 years*area          | -1.74 ( $\pm$ 1.63)       |                    |    |          |
|      | IG 10–40 years*area        | 7.24 ( $\pm$ 6.51)        |                    |    |          |
|      | Arable*area                | 0.18 ( $\pm$ 71.30)       |                    |    |          |

IG, improved grassland

**Table 3.** Estimated probabilities of field occupation by nesting Lapwing according to field-type, on the two transects in 1980 and 1990. Estimates are derived from a logistic regression analysis in which field-type is the only variable considered.

| Field-type       | 1980                      |           |               | 1990                      |           |               |
|------------------|---------------------------|-----------|---------------|---------------------------|-----------|---------------|
|                  | Probability of occupation | 95% CI    | No. of fields | Probability of occupation | 95% CI    | No. of fields |
| Unimproved grass | 0.53                      | 0.35–0.71 | 30            | 0.24                      | 0.10–0.48 | 21            |
| IG < 5 years     | 0.16                      | 0.04–0.50 | 17            | 0.12                      | 0.03–0.38 | 33            |
| IG 5–10 years    | 0.54                      | 0.25–0.84 | 14            | 0.06                      | 0.01–0.40 | 18            |
| IG10–40 years    | 0.09                      | 0.02–0.40 | 19            | 0.12                      | 0.02–0.50 | 16            |
| Arable           | 0.78                      | 0.45–0.95 | 15            | 1.00                      | 0.00–1.00 | 4             |
| Rough grazing    | 0.00                      | 0.00–1.00 | 6             | 0.00                      | 0.00–1.00 | 6             |

IG, improved grassland. The total number of fields studied is less in 1990 than in 1980 due to the afforestation of three fields during this period.

suggested that improved grassland tended to have a lower likelihood of occupation than either unimproved grassland or arable, irrespective of the time since improvement (Table 3). Thus, data from the three improved grassland categories were combined for the purposes of comparison with unimproved grassland and arable (Crawley 1993). Variables that were significant in the full analyses for each year were forced into these analyses. In 1980, the likelihood of field occupation was significantly greater in both unimproved grassland and arable than in improved grassland (change in deviance,  $\Delta D = 4.14$ ,  $df = 1$ ,  $P < 0.05$  for unimproved grassland,  $\Delta D = 15.35$ ,  $df = 1$ ,  $P < 0.01$  for arable), whilst in 1990 the difference was significant only for unimproved grassland ( $\Delta D = 6.85$ ,  $df = 1$ ,  $P < 0.01$  for unimproved grassland,  $\Delta D = 0.01$ ,  $df = 1$ ,  $P = 0.92$  for arable).

### Factors affecting the probability of a field losing nesting Lapwing

The occurrence of drainage increased the likelihood of a field losing nesting Lapwing between 1980 and 1990 (Table 4). When drainage was considered alone, the probability of losing nesting Lapwing was estimated as

0.90 (95% CI: 0.65–0.98) for the 19 fields that had been drained between 1980 and 1990, but only 0.36 (95% CI: 0.09–0.77) for the 22 fields where no drainage occurred during this period. Additionally, during this period, the likelihood of losing nesting Lapwing was higher for fields on the Romano Bridge transect than on the Carllops transect, and increased with field area (Table 4). Whether or not the field had been converted from arable to grass, or had been reseeded (if initially grassland), had no significant effect on the likelihood of losing nesting Lapwing between 1980 and 1990 ( $\Delta D = 2.75$ ,  $df = 2$ ,  $P = 0.25$ ), as was true for slope ( $\Delta D = 0.11$ ,  $df = 1$ ,  $P = 0.74$ ) and altitude ( $\Delta D = 2.29$ ,  $df = 1$ ,  $P = 0.13$ ).

However, as indicated above, drainage and conversion to improved grassland were closely linked. Thus, when drainage was omitted from this analysis the effect of conversion to improved grassland became significant ( $\Delta D = 7.38$ ,  $df = 2$ ,  $P < 0.05$ ). When the effects of conversion to improved grassland were considered alone, the probability of losing nesting Lapwing was estimated as 0.21 (95% CI: 0.06–0.52) for the 14 fields not improved, but as 0.81 (95% CI: 0.39–0.97) for the 16 grassland fields that were reseeded and 0.82 (95%

**Table 4.** Coefficients and changes in deviance for parameters included in minimal adequate models (MAMs) of the probability of a field losing nesting Lapwing during two successive time periods. Detailed field management data were available from 1980 to 1990 only (see text). Models were produced by logistic regression analysis; changes in deviance are those associated with removal of the parameter from the MAM.

| Period    | Parameter              | Coefficient ( $\pm 1$ se) | Change in deviance | df | P      |
|-----------|------------------------|---------------------------|--------------------|----|--------|
| 1980–90   | Constant               | -3.16 ( $\pm 1.36$ )      |                    |    |        |
|           | Occurrence of drainage | 2.28 ( $\pm 0.94$ )       | 6.90               | 1  | < 0.01 |
|           | Transect (Romano)      | 2.33 ( $\pm 1.03$ )       | 6.04               | 1  | < 0.05 |
|           | Field area (ha)        | 0.26 ( $\pm 0.15$ )       | 3.80               | 1  | 0.05   |
| 1990–2000 | Constant               | -0.51 ( $\pm 0.52$ )      |                    |    |        |
|           | Conversion to IG       | 2.30 ( $\pm 1.20$ )       | 4.93               | 1  | < 0.05 |

IG, improved grassland.



CI: 0.32–0.98) for the 11 arable fields that were converted to grass. Between 1990 and 2000, when detailed field management data were lacking, conversion to improved grassland (as determined by the subjective assessment in 2000) was associated with an increased likelihood of losing nesting Lapwing from the field (Table 4). No other effects were significant during this latter period. The MAM produced from the 1980 to 1990 analysis that included the effects of drainage explained 37% of the total deviance in the data on changes in field use, while the MAM for the 1990 to 2000 analysis explained 15% of total deviance.

## DISCUSSION

### Causes of decline

This study documents a long-term decline in the number of breeding Lapwing across a substantial area of upland farmland in southern Scotland, and demonstrates an association between these declines and the increasing intensity of agricultural management in the study area. During the study, nesting Lapwing showed marked preferences for arable (comprising spring-sown crops and ploughed land) and agriculturally unimproved grassland habitats compared with improved grassland, supporting the findings of previous studies (Baines 1988, Galbraith 1989, Wilson *et al.* 2001, O'Brien 2002). These well established habitat preferences suggest that the agricultural intensification of upland farmland has had a detrimental effect on Lapwing populations. Our study provides further evidence for this by demonstrating a temporal association between the agricultural intensification of fields and the loss of nesting Lapwing from these fields.

Drainage was more strongly associated with the loss of nesting Lapwing from fields than the conversion to improved grassland, although the two management practices were closely linked. Wet or damp habitat conditions have been shown to be important features of Lapwing breeding areas in a wide range of previous studies (Berg 1993, Milsom *et al.* 2000, O'Brien 2002). Such habitats may provide more suitable breeding conditions because they hold greater invertebrate food supplies for chicks, or because they are associated with relatively heterogeneous vegetation cover, where the rates of predation on nests and chicks may be lower (Baines 1990, but see O'Brien 2001). Fertilizer inputs may also increase following drainage, leading to greater grassland productivity, which would also occur following reseeded. Thus, during the nesting period,

taller vegetation may have developed in fields from which grazing livestock were absent in spring. Given the dependence of nesting Lapwing on short swards (Milsom *et al.* 2000, O'Brien 2002), this may also have reduced habitat suitability. Alternatively, the more intensive agricultural activities that presumably often followed drainage (e.g. increased sheep stocking densities or more frequent use of machinery) may have been the main mechanisms involved in causing the loss of nesting Lapwing from these fields (Guldemond *et al.* 1995). For example, of 21 nests monitored during one year in four fields in our extensive plot, all failed within two days of the introduction of large numbers of sheep to these fields (I.R.T. pers. obs.). Following the introduction of sheep to the nesting field, these birds appeared to spend much time off their nests and, although losses of Lapwing nests to trampling by sheep tend to be low on upland grasslands (O'Brien 2001), this type of disturbance may lead to higher nest predation rates (Hart *et al.* 2002).

There is considerable evidence implicating agricultural intensification as the major cause of decline in the number of breeding Lapwing in western Europe, and the findings from our study concur with this body of evidence. However, there is also evidence for the involvement of other factors. One study, undertaken across a range of upland farmland sites in northern Britain, found that declines in the number of breeding Lapwing were more closely associated with higher fox abundance than with a shortage of apparently suitable breeding habitat (O'Brien 2001). Furthermore, nest predation rates on these sites were also positively correlated with an index of fox abundance (O'Brien 2001). While there is strong circumstantial evidence that agricultural intensification was the ultimate cause of the observed decline on our study area, the possibility remains that the period of increasing agricultural intensification during which our study was conducted coincided with other changes that caused the number of Lapwing to decline (e.g. increases in predator numbers). In such circumstances it is conceivable, albeit unlikely, that the decreasing numbers of Lapwing were simply redistributing themselves according to the decreasing area of preferred nesting habitat, so accounting for the observed relationship between the agricultural intensification of fields and the loss of nesting Lapwing from these fields.

### Declines in the wider context

Lapwing numbers on our study area declined by 77%

during the 20 years from 1980 to 2000, with the overall extent of decline similar on all three count areas. This finding reflects those from a number of localized studies conducted on upland areas in northern England where declines in the number of breeding Lapwing have been documented over the past 20 to 30 years (McKnight *et al.* 1996, Swindells 1997, Fuller *et al.* 2002). Comparing the findings from the present study with those from more extensive surveys, the decline of 38% recorded between 1990 and 2000 in our study is less marked than that recorded across England and Wales between 1987 and 1998 and across Northern Ireland over a similar period (see Introduction). However, the declines on our study area had been ongoing since at least 1980, when the study began, and on two of the three count areas the rate of decline was greatest during the earlier period of study. Interestingly, during the earlier period of the study (1980–90) the declines were also substantially greater than the 38% decline recorded from lowland wet meadows in England and Wales between 1982 and 1989 (O'Brien & Smith 1992).

In contrast to our results, recent extensive surveys across Scotland suggest minor declines at most in the number of breeding Lapwing in Scotland, with a non-significant decline of 8% recorded between 1992 and 1997 (O'Brien *et al.* 2002). While our study area may be atypical, the period of greatest decline in Lapwing numbers on our study area occurred before the relatively short period over which trends across Scotland have been assessed. Thus, data on the changes in Lapwing numbers across Scotland may have been obtained following a period of substantial decline.

The findings from our study suggest that agricultural intensification was driving the observed decline in Lapwing numbers, so that these declines are more likely to be representative of other upland areas of Scotland if the land-use changes recorded on our study area are typical of those elsewhere. The use of roads as transects could have led to the sampling of an unrepresentative range of fields, but the decline in Lapwing numbers recorded on these transects was reflected on the extensive area that was also monitored. This suggests that the transects were at least representative of the wider area around them. The greatest changes in agricultural management on our study area appeared to occur between 1980 and 1990, a period of increased agricultural intensification in certain other upland regions of Scotland (Mowle & Bell 1988, Grant 1992). However, between 1990 and 2000 changes in agricultural management appeared to be less marked and

this coincided with the cessation of the Farmer and Conservation Grant Scheme in 1996/97, which through both national and EU funding sources had promoted drainage and reseeded works throughout Scotland in earlier years (SEERAD pers. comm.). This suggests that the trends in agricultural management recorded on our study area may have been representative of many other areas of upland farmland. Despite this, June Agricultural Census data show no increase in the total area of grassland of less than five years old between the early 1980s and the early 1990s, either for Scotland overall or for southern Scotland only (SEERAD unpubl. data), although these data do not distinguish changes on upland farmland from those elsewhere.

Clearly, it is difficult to assess the extent to which the observed declines in the number of breeding Lapwing on our study area are representative of changes in Lapwing numbers in other upland areas of Scotland. However, combining the findings of our study with those from similar studies on other upland areas of the UK provides strong indications of marked declines in the number of breeding Lapwing in several upland areas where the species was previously abundant.

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